



EXECUTIVE SUMMARY

# SAN FRANCISCO BAY MICROPLASTICS PROJECT

Microplastics (particles less than 5 mm) are ubiquitous and persistent pollutants in the ocean and a pervasive and preventable threat to the health of marine ecosystems. Microplastics come in a wide variety of shapes, sizes, and plastic types, each with unique physical and chemical properties and toxicological impacts. Understanding the magnitude of the microplastics problem and determining the highest priorities for mitigation require accurate measures of microplastic occurrence in the environment and identification of likely sources.

To develop critical baseline data and inform solutions, the San Francisco Estuary Institute and the 5 Gyres Institute have completed the first comprehensive regional study of microplastic pollution in a major estuary. This project supported multiple scientific components to develop improved knowledge about and characterization of microparticles and microplastics in San Francisco Bay and adjacent National Marine Sanctuaries, with the following objectives.

1. Contribute to the development and standardization of sample collection and analysis methodology for microplastic transportation research.
2. Determine a baseline for future monitoring of microplastics in San Francisco Bay surface water, sediment, and fish, and in ocean waters outside the Golden Gate.
3. Characterize pathways by which microplastics enter the Bay, including urban stormwater and treated wastewater effluent.
4. Investigate the contribution of Bay microplastics to the adjacent National Marine Sanctuaries through computer simulations.
5. Communicate findings to regional stakeholders and the general public through meetings and educational materials.
6. Facilitate evaluation of policy options for San Francisco Bay, with recommendations on source reduction.

This document presents the findings of this three-year project. A companion document, "San Francisco Bay Microplastics Project: Science-Supported Solutions and Policy Recommendations," has been developed by 5 Gyres using the findings of this study (Box and Cummins, 2019).

PROJECT PARTNERS **San Francisco Estuary Institute** • **The 5 Gyres Institute**

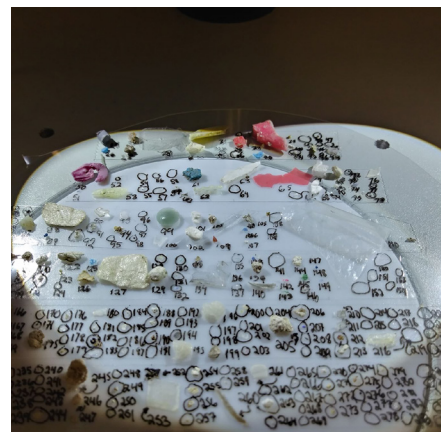
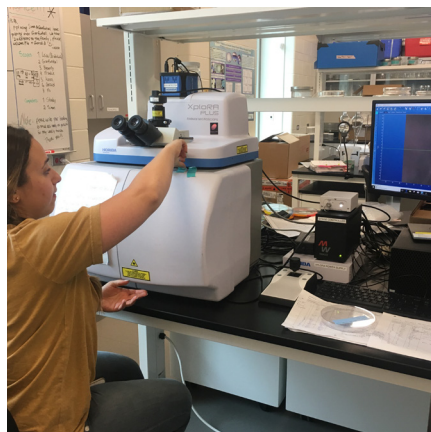
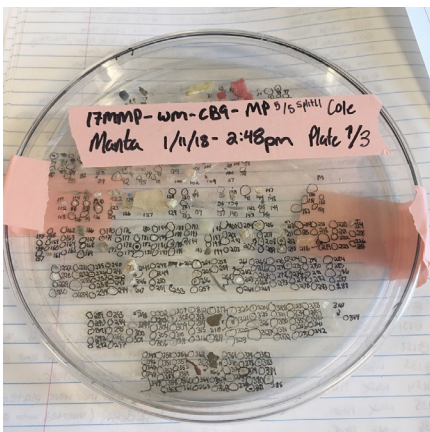
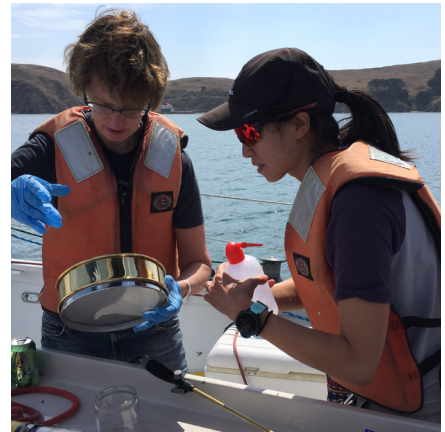
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## Our Findings

In this report, we have distinguished between microparticles, which are small particles (less than 5 mm) that are visually identified as potentially plastic, and microplastics, which are confirmed to be plastic through Raman or Fourier Transform Infrared (FTIR) spectroscopy. This distinction is necessary because it was not possible to examine every microparticle via spectroscopy to confirm particle composition. Moreover, for some particles, clear spectra were not easy to obtain.

Microparticles and microplastics come in a range of sizes, and the lower size limit of microplastics within a sample is operationally defined by the mesh, sieve, or filter pore size used in sample collection and analysis. We quantified microparticles using sieves with a mesh size of 0.125 mm for stormwater, wastewater, and sediment. For surface water, the standard manta trawl sample collection method typically captures particles greater than 0.355 mm, whereas for prey fish, it is possible to collect far smaller particles. When smaller size fractions are included, the overall number of microparticles and microplastics in a sample can increase significantly. To facilitate comparisons among these different types of samples, particles were grouped into uniform size categories during laboratory analysis.





## STORMWATER

We measured microparticles and microplastics in stormwater from 12 small tributaries comprising 11% of the watershed drainage area to San Francisco Bay (6% of total flow to Bay). These tributaries varied in urban and non-urban land uses and were distributed across the region.

Microparticles were identified in stormwater from all 12 small tributaries, which discharged between 1.3 and 30 microparticles per liter. Fragments (59%) and fibers (39%) constituted nearly all microparticles sampled.

Nearly half of the particles from field samples were black fragments that had a distinctive rubbery texture when handled with tweezers. Spectroscopic analysis and secondary characteristics suggested these particles may be synthetic or natural rubber. This identification is not definitive, as other techniques beyond the scope of this project are needed to confirm the particle composition. For purposes of this report, these polymers are considered a type of plastic, a common approach in the field of microplastics. The literature suggests that one potential source of these particles is vehicle tire wear.

Using an existing stormwater model developed for other contaminants, we estimated the annual discharge of microparticles via stormwater from small tributaries to be 11 trillion microparticles to the Bay. Approximately two thirds of these microparticles were estimated to be plastic, yielding an estimated annual discharge of 7 trillion microplastics per year. This estimate of microplastic load is approximately 300 times greater than the estimated annual discharge from all wastewater treatment plants discharging into San Francisco Bay.



## TREATED WASTEWATER

We measured microparticles and microplastics in treated wastewater from eight wastewater treatment facilities that represent approximately 70% of the treated effluent flow discharged to San Francisco Bay. These facilities are geographically distributed, vary in effluent treatment capacity, and employ a range of treatments. Microparticles were identified in effluent from all eight facilities, which discharged an average of 0.063 microparticles per liter. Fibers were the most frequently identified type. While 19% of the fibers were unmistakably plastic, another 50% were clearly manufactured due to the presence of dyes and coloring agents, but could not be definitively identified as plastic or non-plastic. Fragments were the second most abundant shape, and of those that underwent spectroscopy, 54% were identified as plastic, with most being polyethylene (31%).

In aggregate, approximately 91 million microparticles per day are discharged by the eight facilities. Facilities employing advanced treatment including dual media filtration had lower microparticle concentrations than facilities without this additional treatment, suggesting that enhanced treatment may reduce microparticles as well as other pollutants. Assuming similar discharges among the remaining facilities, approximately 130 million microparticles are discharged per day to the Bay in treated wastewater effluent, or approximately 47 billion microparticles annually, of which 17 billion are estimated to be plastic. This is substantially lower than the estimate developed for the annual microplastic load from the small tributaries surrounding the Bay.

## SURFACE WATER

We collected surface water samples at 17 monitoring sites throughout San Francisco Bay and 11 monitoring sites within the Monterey Bay, Cordell Bank, and Greater Farallones National Marine Sanctuaries. Each site was sampled twice, once during the dry season and again during the wet season following rainfall events.

Microparticles were identified in all manta trawl samples, with higher abundances overall in the Bay than in the adjacent marine sanctuaries. Levels of microparticles in the Bay were some of the highest observed globally to date. The dominant particle type was fibers, followed by fragments, with 53% of fibers and 87% of fragments identified as plastic. The composition of many fibers could not be determined, though the presence of dyes and coloring agents indicated that they were anthropogenic in origin.

Apart from fibers, polyethylene and polypropylene fragments, polystyrene foams, and polyethylene and polypropylene films made up a majority of the microparticles that underwent spectroscopy. These polymer and particle types may be linked to the breakdown of single-use plastic items, packaging, and plastic bags. Polyethylene beads were also identified in surface water, possibly linked to microbeads found in personal care and cleaning products.

Wet season Bay samples contained statistically higher concentrations of microparticles compared to dry season samples, suggesting that wet weather may mobilize microplastics from the surrounding watershed. Within the Bay, the wet season average abundance for non-fiber particles was 520,000 microparticles/km<sup>2</sup>, while the average for fibers was 580,000 microfibers/km<sup>2</sup>. A statistically significant seasonal effect was not observed in the sanctuaries, likely due to the low abundance of microparticles observed.

Manta trawl sample collection is not an ideal method for capturing fibers. Sampling methods designed to collect more representative levels of fibers, as well as especially small particles, were deployed at some sites to test their effectiveness. However, field blank samples collected and analyzed to monitor background contamination for these sampling techniques had high levels of microparticles, especially fibers. This suggests the need for sampling larger volumes and provides further evidence of the impacts of background contamination from fibers on data quality.



## *SEDIMENT*

We collected sediment samples at 20 sites, including 18 within San Francisco Bay and two in Tomales Bay, which has minimal urban influence. Sites were selected to characterize microplastic concentrations near discharges of stormwater and wastewater in the nearshore “margins” of the Bay, in open portions of the Bay, and in a less urban reference area (Tomales Bay).

Microparticles were identified in sediment from all 20 sites. Fibers, followed by fragments, were the most abundant type of microparticles in Bay sediment, with detected concentrations ranging between 1 and 49 microfibers per gram dry weight (dw), and between 0.1 and 11 non-fiber microparticles (including fragments, films, spheres, and foams) per gram dw. The highest concentrations of microparticles were measured in Lower South Bay, which is strongly influenced by wastewater and urban stormwater discharges. Concentrations at the reference site, Tomales Bay, were among the lowest observed in the study.

Black fragments that had a rubbery texture were frequently detected in sediment samples. Spectroscopy was unable to identify the composition; however, based on secondary characteristics, these particles were similar to particles that had been previously identified as rubber by FTIR spectroscopy. These particles were also similar to the black, rubbery fragments that were abundant in stormwater, suggesting that stormwater is an important pathway for microparticles to reach Bay sediment, and that inputs from tire wear and perhaps use of recycled tires (e.g., artificial turf) also merit further investigation.

Microparticle and microplastic concentrations in Bay sediment were higher than those reported in the majority of other regions around the globe.



## PREY FISH

To evaluate the uptake of microplastics into the food web, two prey fish species, topmelt and northern anchovy, were sampled at six sites in the Bay, as well as two sites in a less urban reference area (Tomales Bay). At each site, approximately 10 fish of each species were collected, and the digestive tracts were analyzed for microparticles and microplastics.

Microparticle levels in fish from San Francisco Bay were higher than levels in fish from Tomales Bay. Fibers were particularly abundant; while most fibers were dyed and therefore produced by humans, few could be identified conclusively as plastic. At least 38% of fish from the Bay had consumed microparticles.

The estimated average number of microplastics was between 0.2 and 0.9 non-fiber microplastics per fish and between 0.6 and 4.5 plastic fibers per fish. While fibers were detected in all fish from the Bay regardless of species, non-fiber microparticles were more frequently detected in topmelt compared to anchovies. The microplastic counts and detection frequencies in the Bay were comparable to counts reported in many other locations.

While toxicological evaluation was not a part of this study, these results indicate that microplastics are entering Bay food webs. Microplastics have been shown to transfer up food chains and cause adverse effects in fish, but the magnitude and types of effects are difficult to predict because of the diversity of microplastic morphologies and compositions. There is a need for further ecotoxicological studies that evaluate the effects of microplastics at environmentally relevant concentrations. However, even with more ecotoxicological data, establishing risk thresholds will be challenging given the heterogeneous nature of this class of contaminants.

## **TRANSPORT MODEL**

A novel three-dimensional hydrodynamic transport model was developed to simulate microparticle and microplastic movement in the Bay and the adjacent marine sanctuaries. The model was validated and accurately captured water surface elevations, velocities, and salinity. This model is unique in its spatial coverage from small scale (e.g., meters) in sloughs and mudflats within the Bay to shelf-scale (e.g., tens of kilometers) dynamics in the coastal ocean. The transport model includes the effects of wind and tides, as well as inflows from stormwater, wastewater, and freshwater from the Sacramento-San Joaquin River Delta.

The model incorporated estimated microparticle and microplastic loads from stormwater and wastewater, and simulated particle trajectories throughout the Bay and into the coastal ocean. The rising and settling characteristics of particles were estimated based on laboratory measurements of chemical composition, shape, and size.

Model output was analyzed to estimate spatial distributions of predicted surface water concentrations and potential deposition to sediment, as well as time scales for particles to be exported from the Bay. The fate of microplastics was found to be highly sensitive to particle buoyancy, and even minimal sinking rates led to retention of particles within the Bay. The model indicated that, for microplastics originating in San Francisco Bay, only buoyant particles were likely to travel any significant distance beyond the Golden Gate and into the nearby National Marine Sanctuaries. The transport model and the manta trawl particle abundance data were in good agreement, showing that the average abundance of particles was higher in the Bay than in the coastal ocean. Good agreement was also observed between the model-predicted microparticle abundances near the bottom of the Bay and measured sediment concentrations, showing the greatest abundance of microparticles in Lower South Bay.

## **CONCEPTUAL MODEL AND DATA SYNTHESIS**

We refined a conceptual model of major pathways of microplastic pollution for San Francisco Bay, including a comprehensive review of likely sources to urban stormwater runoff and treated wastewater discharges. This study synthesis indicated identification of specific plastic polymers is essential for pinpointing potential sources of microplastics, as well as predicting the movement of these particles within and through estuarine ecosystems.

Comparison of urban stormwater and wastewater indicated that beyond the large differences in estimated loads to the Bay, there were also considerable differences in relative proportions of different polymers. The large contribution of black, rubbery fragments was a dominant feature in urban stormwater samples. Meanwhile, wastewater samples indicated influence from multiple sources, including plastics used in textiles (acrylic, polyester), as well as microbeads in personal care and cleaning products and microplastics likely derived from the breakdown of larger single-use items (polyethylene).



Comparison of surface water and sediment samples likewise indicated that polymer type was generally the most influential variable in determining whether relative contributions of different types of microplastics were preferentially concentrated in one matrix or the other. Buoyant polymers and foams were more likely to be found in surface water, while denser particles were often found in sediment.

Key data gaps for San Francisco Bay remain, including additional information on the sources and pathways of microplastics, the exposure of Bay aquatic organisms and associated risk for adverse impacts, more comprehensive information resulting from essential improvements in methodology, and the effects of current and future solutions implemented to reduce microplastic pollution.

### **LESSONS LEARNED: RECOMMENDED BEST PRACTICES FOR FUTURE STUDIES**

The field of microplastics pollution is in its infancy, and there are not yet widely accepted standards for sample collection, laboratory analysis, quality assurance/quality control (QA/QC), or reporting of microplastics in environmental samples. This project included the development of recommended best practices for collection, processing, analysis, and reporting microplastics in environmental media. We recommend factors to consider in microplastic study design, particularly in regard to site selection and sampling methods. We also highlight the need for standard QA/QC practices such as collection of field and laboratory blanks, use of methods beyond microscopy to identify particle composition, and standardized reporting practices, including suggested vocabulary for particle classification.

This summary is from *Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region* (Sutton, et al., 2019). The full report can be downloaded from our project website: <https://www.sfei.org/projects/microplastics>.

Reference: Sutton, R.; Franz, A.; Gilbreath, A.; Lin, D.; Miller, L.; Sedlak, M.; Wong, A.; Box, C.; Holleman, R.; Munno, K.; Zhu, X.; Rochman, C. 2019. *Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region*. SFEI Contribution No. 950. San Francisco Estuary Institute: Richmond, Calif.

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